Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 121 (2015) 1642 – 1649

Procedia Engineering

www.elsevier.com/locate/procedia

9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) and the 3rd International Conference on Building Energy and Environment (COBEE)

Study on Daylighting and Energy Conservation Design of Transparent Envelope for office building in Hot Summer and Cold Winter Zone

Jinghua Yu[a,*], Yu Liu[a], Chao Xiong[a], Jun chao Huang[a]

[a]*School of Environmental Science and Engineering, Huazhong UniversityofScience and Technology, Wuhan, China*

Abstract

The design of transparent envelope not only affects the energy consumption of cooling and heating, but also has a great impact on indoor day lighting (lighting energy consumption), artificial lighting in office building energy consumption counts for the important proportion, and influences the energy consumption for cooling and heating, so it is necessary to study the energy-saving optimal design of transparent envelope for office building. Combined with day lighting, the effects of some parameters on overall energy consumption of cooling, heating and lighting are investigated using simulation software, such as the window to wall ratio, the heat transfer coefficient of window, shading coefficient, transmittance, shading system, and so on, the optimal design of transparent envelope is obtained for office buildings of the summer and cold winter zone. The results show that annual total energy consumption is the lowest when the window to wall ratio is 40% in different window to wall ratios, building facade facing south among different orientations, and the type is on-2/3-1/3-off in different control methods.

Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015

Keywords:Transparent envelope, optimal design, day lighting, energy consumption, window to wall ratio;

1. Introduction

Office building design has become a growing diversity, the window to wall ratio design gradually increased, the design of transparent envelope not only affects the energy consumption of cooling and heating, but also has agreat

* Corresponding author. Tel.: +86-159-7200-7990 ; fax:+86-027-87792101.
*E-mail address:*yujinghua323@126.com

Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015
doi:10.1016/j.proeng.2015.09.108

impact on indoor day lighting, such as increasing window area of office building is beneficial to indoor lighting (can reduce indoor lighting energy consumption). Decreasing lighting energy consumption also can reduce cooling load. At the same time, increasing window area can increase indoor solar radiation heat gain that can increase cooling load and reduce heating load. So transparent envelope design affects the energy consumption of cooling, heating and lighting, it needs to integrate three final energy consumption results to achieve energy optimization design of transparent envelope.

There have a lot of research about thermal performance of transparent envelope of office building. The studies main focus on types of windows or skylights and on insulation level of shading devices, including window to wall ratio, the heat transfer coefficient of window, shading coefficient and windows integrated energy research [1-5]. For the studies on natural day lighting, most of them are focused on design problem and the analysis of lighting energy consumption under the most unfavorable working conditions [6-10], still lacks of studies about transparent envelope designed comprehensive impact on lighting energy consumption and air-conditioning heating energy consumption. Combined with day lighting, using simulation software eQUEST to investigate the effects of some parameters on overall energy consumption of cooling, heating and lighting. The parameters include window to wall ratio, building orientation, shading coefficient, visible light transmittance, the heights of window and windowsill, and the control method of lighting. At last, the most energy efficiency design that is fit for hot summer and cold winter zone is achieved.

2. Base case model

A six-story typical bar building is selected; the typical floor is shown in Figure 1. The building area is 5394.5m2, the window to wall ratio is 30% and the type of window is Clear/thin air/clear, double insulating glass, 3mm transparent glass. Heat transfer coefficient is 3.1W/(m^2K). Shading coefficient is 0.55. Wall structure: 200mm reinforced concrete+25mm extruded polystyrene. Its inner surface is plaster, and the heat transfer coefficient is 1.0. Roof structure: 9mm roof layer (concrete)+38mm extruded polystyrene +150mm heavy concrete+30mm lightweight concrete, its heat transfer coefficient is 0.65, the interior wall heat transfer coefficient is 2.28 (13mm gypsum plaster +interior wall components+1.3cm gypsum plaster). The floor is of reinforced concrete and its' heat transfer coefficient is 1.8 (100mm concrete HW140LB+32mm concrete LW 30 LB).

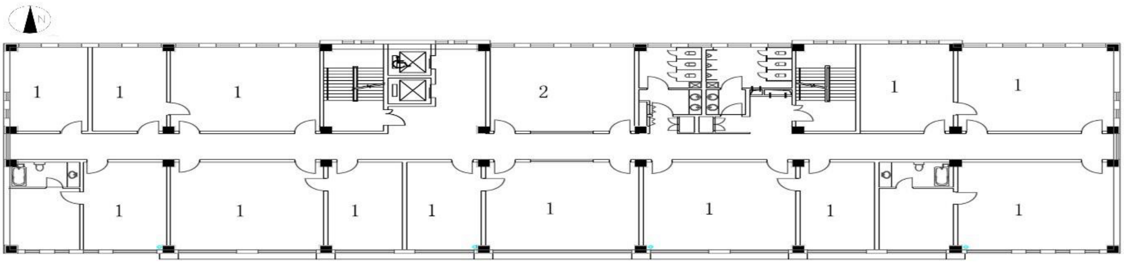

Fig.1. Typical floor plane of building (1-Office, 2-Anteroom).

3. Design conditions

The mode of heating, cooling is intermittent home air-source heat pump air conditioners (VRF heat pump air conditioning units). Its summer energy efficiency ratio takes 3.1 during cooling period, and 3.0 during heating period, moreover, when indoor temperature meets the set temperature, it automatically stops running. Running time is from Monday to Friday, 8:00 am to 6:00 pm. According to the stipulations of the "public building energy efficiency design standard"(MCPRC 2005), the room temperature is set 25 ℃ for cooling and 20℃ for heating. Air changes of throughout the year is 1 times/h. Supply air temperature is 15℃and 30℃respectively. Personnel fresh air equivalent to ventilation frequency, offices and corridors is 2.2 and 0.18 respectively. Cooling period in Wuhan is from Jun. 1st to Sep. 15th and heating period is from Dec. 1st to Feb. 28th.

The control of lighting system is on-off, indoor analysis points located 67% of from the window into the depths, and distance roof is 0.76m. When the intensity of illumination is lower than 500lux, it automatically opens the light. The office building lighting density setting, personnel density setting and comprehensive equipment heat load settings as shown in Table 1.

Table 1. Basic settings.

	Illumination intensity(w/m^2)	Comprehensive equipment heat load(w/m^2)	Personnel density(m^2/person)
General office	11	20	4
Corridor	5	0	50
WC	11	5	20
Anteroom	11	20	4

4. Results

4.1 Window to wall ratio

Fig. 2 shows that when considering the influence of the daylighting, the effect of window to wall ratio on the lighting energy consumption. For base case model, the cooling energy consumption is 155.5MWh, the heating energy consumption is 92.48MWh, lighting energy consumption is 79.38MWh and the total energy consumption is 327.36MWh. Compared with using illumination system all day, its total energy consumption is reduced by 20.3%. With the increase of window to wall ratio, lighting energy consumption is reduced. The total energy consumption reduces first and then increases. When the window to wall ratio is 40%, the total energy consumption is the lowest, only 323.53MWh, it is decreased by 1.17% compared with the base case building.

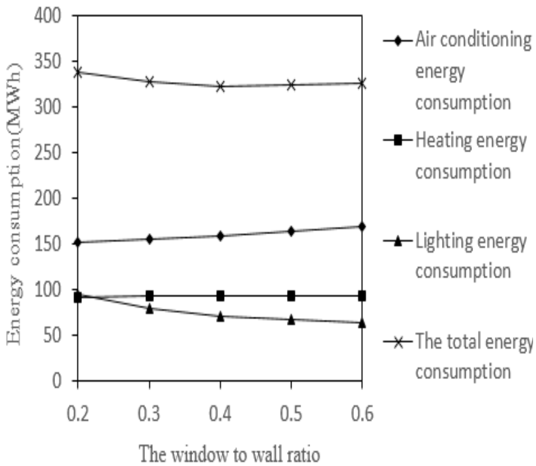

Fig. 2. The influence of window to wall ratio on total annual energy consumption.

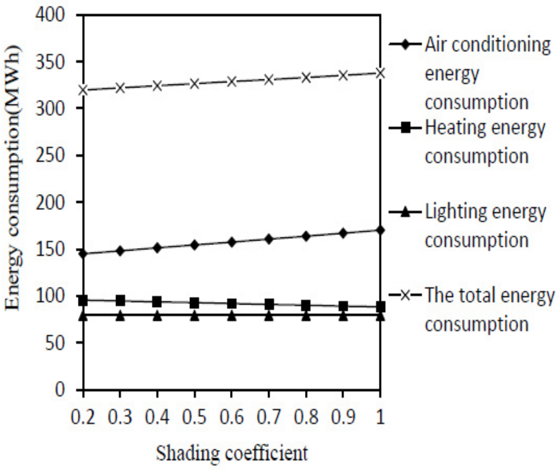

Fig.3. The influence of shading coefficient on total annual energy consumption.

4.2 Shading coefficient

With and without considering daylighting, shading coefficient has no influence on lighting energy consumption. However, it has a great influence on cooling and heating energy consumption. Its influence trend is shown as Fig. 3

With the increase of shading coefficient, the heat gain of solar radiation increases, the cooling energy consumption in summer increases, heating energy consumption in winter reduces and the annual total energy consumption increases. From Fig. 3, compared with base case model (shading coefficient 0.55), when the shading coefficient is 1.0, the cooling energy consumption is increased by 9.45%, the heating energy consumption is reduced by 4.39%, the total annual energy consumption is increased by 3.11%. Moreover, when the shading coefficient is 0.2, the cooling energy consumption is reduced by 6.77%, the heating energy consumption is increased by 3.30%., and the total annual energy consumption is reduced by 2.32%.

4.3 Visible light transmittance

Visible light transmittance has a significant influence on energy consumption of lighting; the change of lighting energy consumption affects the cooling and heating load and energy consumption. The higher the visible light transmittance is, the more the visible light comes into the room, and lower the lighting energy consumption is. Furthermore, reduce the energy consumption of cooling; increase the energy consumption of heating. In the numerical, the amount of energy consumption of heating has a slight increase. Fig. 4 shows that compared with the base case model(visible light transmittance is 0.67), when the visible light transmittance increases to 1.0, energy consumption of cooling is reduced by 0.90%, energy consumption of heating is increased by 0.29%, energy consumption of lighting is reduced by 14.46%, the total annual energy consumption can be reduced by 3.75%. When the visible light transmittance is 0.2, energy consumption of cooling is increased by 4.51%, energy consumption of heating is reduced by 1.57%, energy consumption of lighting is increased by 67.75%, and the total annual energy consumption is increased by 18.21%. It can be seen that visible light transmittance has greater impact on total energy consumption than shading coefficient.

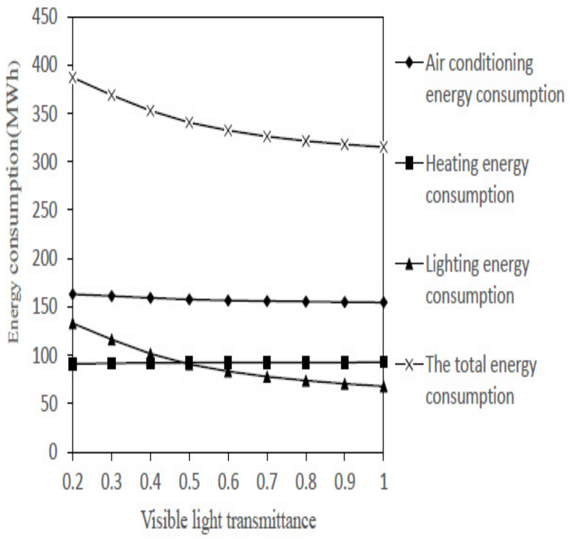

Fig. 4. The influence of visible light transmittance ontotal annual energy consumption.

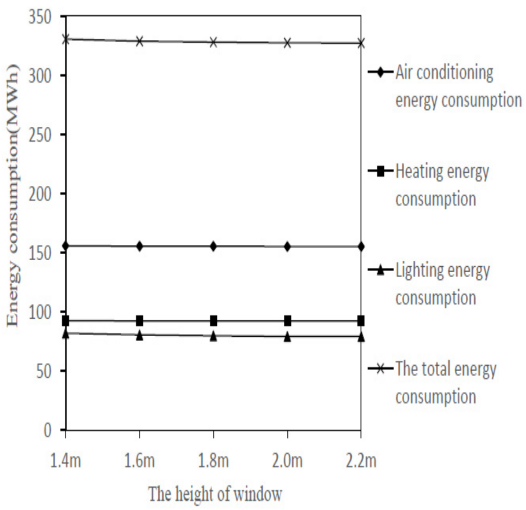

Fig. 5. The influence of window heighton total annual energy consumption.

4.4 Heights of the window and window still

The height of the window affects the position of visible light into the room, so it affects the energy consumption of lighting. Moreover, it has a little impact on energy consumption of cooling and heating. With the increase of the window height, interior room (away from the window) illumination intensity increases. Due to the lighting system is automatic start-stop control, energy consumption of lighting and cooling is reduced, energy consumption of heating is almost unchanged, the total energy consumption is slightly reduced. Fig. 5 shows that when the height of the window is reduced to 1.4m from 2.1m (basic building, window sill height is 1 m), energy consumption of cooling is increased by 0.43MWh, accounts for 0.28%. Heating energy consumption is increased 0.13MWh, accounts for 0.14%, lighting energy consumption is increased by 2.74MWh, accounts for 3.45%. Total annual energy consumption is increased by 3.3MWh, 1.01% of total. So the height of the window has a greater effect on lighting energy consumption than the cooling and heating energy consumption.

Window sill height has an impact on lighting energy consumption, changes of lighting energy consumption lead to little changes of cooling and heating energy consumption. Fig. 6 shows that with the increase of the height of the window sill, lighting energy consumption increases cooling energy consumption also increases, but heating energy consumption reduces, and total energy consumption increases. When the height of the window is reduced to 0.4m from 1.0m, lighting energy consumption is increased by 8.92MWh, accounts for 11.24%. Cooling energy consumption is increased 1.1MWh, accounts for 0.71%. Heating energy consumption reduced is 0.28MWh, accounts for 0.3%. Total annual energy consumption is increased by10.34MWh, which is 2.98% of total.

4.5 Building orientation

Fig. 7 shows that when building orientation changes, the total energy consumption has a slightly change. For the bar building, when building headed for the south, the minimum total energy consumption is 327.67MWh, followed by the southwest and north. Energy consumption of building which facing east is up to 337.1MWh. When building headed for the southwest, lighting energy consumption is the lowest; when the building towards the south, the heating energy consumption is the lowest; when the building towards the north, the cooling energy consumption is also the lowest. Therefore, building oriented north and south is suitable for hot summer and cold winter area.

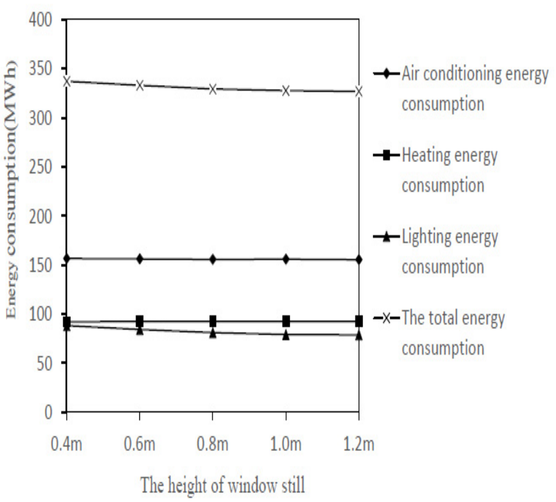

Fig.6. Theinfluence of height of window still on total annual energy consumption.

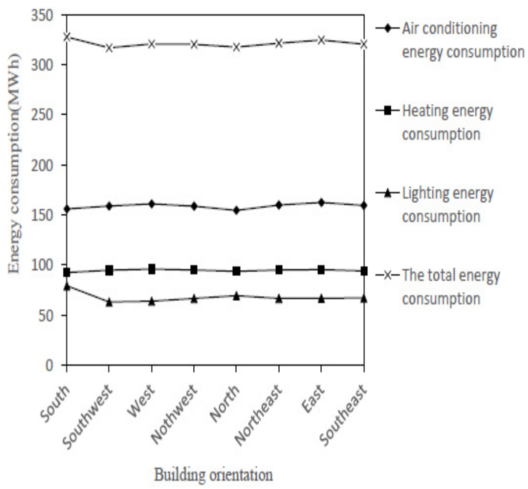

Fig.7. Theinfluence ofbuilding orientationon total annual energy consumption.

4.6 Control methods

Six kinds of specific control methods include on-off control, indoor lighting gradually change to 30% (it is the input power increases or decreases gradually, the lowest is 30%), Full-1/2-off, Full-1/2, Full-2/3-1/3-off, Full-2/3-1/3. Fig. 8 shows that stage on-off control is better than on-off control; the following is the continuous control, the stage control (no close control) leads to the highest energy consumption. In these control mode, the total energy consumption and lighting energy consumption from high to low order is Full-1/2, Full-2/3-1/3, gradually decrease to 30%, on-off control, Full-1/2-off, Full-2/3-1/3-off.

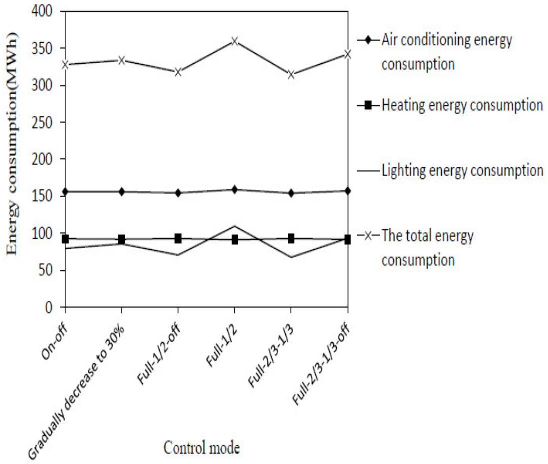

Fig.8. The influence of control methodson the total energy consumption.

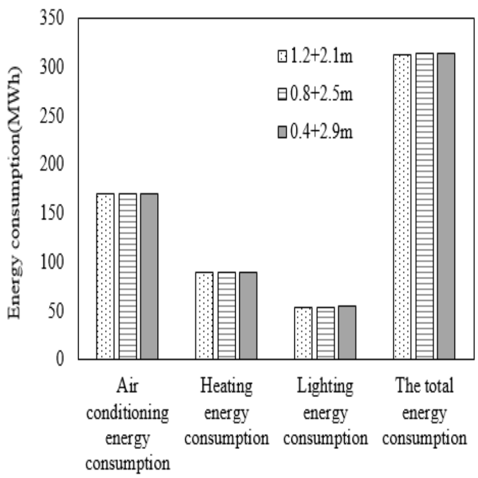

Fig. 9. The window edge height (Windowsill height + window height)impact on the total energy consumption.

5. Discussion

According to the above analysis, visible light transmittance has greater impact on total energy consumption than other factors, epically on the lighting energy consumption. Shading coefficient has no influence on lighting energy consumption. However, it has a great influence on cooling and heating energy consumption. the lower the shading coefficient is, the lower the cooling energy consumption is ,and the higher the heating energy consumption is, Therefore, in hot summer and cold winter area, low shading coefficient is better for the cooling period is longer, this conclusion is the same with the previous study[12] .

The effects of window to wall ratio on cooling/heating energy consumption and lighting energy consumption are both great, with the increase of window to wall ratio, lighting energy consumption is reduced sharply, this is because the intensity of interior day lighting increases, when it reaches 500lux, lighting system automatically turn off, the lighting energy consumption decreases significantly; with the increase of window area, the cooling and heating energy consumption increases, while, the increase of day lighting can increase the cooling load and decrease the heating load, so the effect of window to wall ratio on cooling energy consumption is more obvious than heating energy consumption.

The heights of the window and window still, as well as the visible light transmittance, have a greater effect on lighting energy consumption than the cooling and heating energy consumption. With the height of window increase and the height of the window sill increase, the total energy consumption decreased. Therefore, when the height of window edge keep certain, the energy performance for different combination of window height and window still is shown in figure 9, keep sill height + window height 3.3m, (a)sill height is1.2m, window height is 2.1m, (b)sill height is 0.8m, window height is 2.5m, (c)sill height is 0.4m, window height is 2.9m. The results show that the three total annual energy consumptions have little difference; case (a) is the lowest. When the height of window edge and the window area keep constant, the higher sill height is, the lower the total annual energy consumption is. Increasing the sill height has larger effect on reduction of total energy consumption than increasing window height. From the above analyses also can be seen sill height is more obvious influence.

According to the analysis, the optimal design scheme should be that the window wall ratio is 40%, building facade heads for the south, control mode is on-2/3-1/3-close stepped off control, sill height is 1.2m, window height is 2.1m and window with high visible light transmittance, low shading coefficient, and low coefficient of heat transfer is selected. Wuhan city belong to hot summer and cold winter area, MCPRC (2005) stipulates the maximum heat transfer coefficient and shading coefficient of window, and window to wall ratio, 12 types of double glazing are selected, the parameters are shown in Table 2.

Various cases of cooling, heating and lighting energy consumption and the total energy consumption are shown in Table 3. It can be seen from this table, the total energy consumptions are much lower when buildings with Low-e glazing of type 11 and 12, Because the low heat transfer coefficient and shading coefficient, high visible light transmittance are shown for the Low-e glazing. Followed by 3mm floating green/air /clear glass (type 10) and 6mm transparent/air/transparent (type 3), because the visible light transmittance is high; while heat transfer coefficient has little effect on the total energy consumption (such as the type 10 and 12, the type 4 and 5).

Table 2. Parameters of various glazing.

	Glazing type	K($W/(m^2 \cdot K)$)	SC	VT
1	3mm raregases transparent insulating glass	3.12	0.85	0.81
2	3mm ordinary transparent insulating glass	2.72	0.97	0.81
3	6mm ordinary transparent insulating glass	2.67	0.79	0.79
4	3mm dark grey /thin air / transparent glass	3.12	0.37	0.23
5	3mm dark grey /air / transparent glass	2.72	0.36	0.23
6	6mm dark grey /air / transparent glass	2.67	0.24	0.08
7	3mm darkgrey/air/low-eheat-reflective glass	2.50	0.33	0.21
8	3mm brown /air / transparent glass	2.72	0.71	0.61
9	6mm brown / air / transparent glass	2.72	0.57	0.48
10	6mm floating green /air /transparent glass	2.72	0.66	0.75
11	3mmlow-e glass /air /transparent glass	1.70	0.47	0.72
12	3mmlow-e-178/air/transparent glass	1.76	0.66	0.70

The total energy consumption of clear glazing (type 1 and 2) and brown double glazing (type 8, 9) is not high, due to the visible light transmittance and shading coefficient are high or not too low. Dark grey surface of the double glazing leads to higher energy consumption, the reason is that these windows are very low visible light transmittance, only 0.21-0.23. So we should choose the glazing with low heat transfer coefficient, low shading coefficient, and high visible light transmittance. The impact of visible light transmittance is the greatest.

Table 3.Examples of various glazing of total annual energy consumption.

Window Types	1	2	3	4	5	6
Cooling energy consumption(MKW)	169.98	170.08	167.47	155.52	154.61	156.08
Heating energy consumption(MKW)	90.73	89.47	89.88	93.86	92.97	92.96
Lighting energy consumption(MKW)	53.75	53.75	54.33	85.58	85.58	131.61
The total energy consumption(MKW)	314.46	313.3	311.68	334.96	333.16	380.29
Window Types	7	8	9	10	11	12
Cooling energy consumption(MKW)	153.38	164.42	159.59	162.64	153.99	161.52
Heating energy consumption(MKW)	92.41	90.74	91.59	91.06	89.24	87.73
Lighting energy consumption(MKW)	89.02	58.1	62.74	54.86	55.8	54.66
The total energy consumption (MKW)	334.81	313.26	313.92	308.56	299.03	303.91

6. Conclusions

According to the analysis, annual total energy consumption is the lowest when the window to wall ratio is 40% in different window to wall ratios, building facade facing south among different orientations, and the type is on-2/3-1/3-off in different control methods. The glazing with low shading coefficient and high visible light transmittance leads to lower annual energy consumption. With the increase of the window height and the window sill height, the total energy consumption is decreased. When the height of the window edge keep constant (window to wall ratio are the same), increasing the height of the windowsill to reduce the total energy consumption is more obvious. Due to the lower heat transfer coefficient, lower shading coefficient and higher visible light transmittance, low-e is the best glazing in various kinds of windows. Among the three thermal parameters of glazing, visible light transmittance has the greatest impact on total energy consumption.

Acknowledgements

The research work presented in this paper is financially support by the Doctoral Funds for Higher Education of China (Grant No. 20110142120084), the National Natural Science Foundation of China (Grant No. 51208221) and the Fundamental Research Funds for the Central Universities, HUST (Grant NO. 2015QN119).

References

[1] Z.Z. Wu, Design and research on energy conservation of multilayer office buildings in Wuhan region, Master Thesis, Wuhan University of Technology, Wuhan, 2008, 65 pages.
[2] G.A. Florides, Measures used to lower building energy consumption and their cost effectiveness, Appl Energ.73 (2002) 299-328.
[3] C.K. Cheung, R J. Fuller, M.B. Luther, Energy-efficient envelope design for high-rise apartments, Energ Buildings. 37 (2005) 37-48.
[4] R.M.J. Boke, The effect of window position and window size on the energy demand for heating, cooling and electric lighting, in: 10th International Building Performance Simulation Association Conference and Exhibition, Beijing, China, 2007, pp.117-121.
[5] K. Tsikaloudaki, Assessing cooling energy performance of windows for office buildings in the Mediterranean zone, Energ Buildings. 49(2012) 192-199.
[6] A. Tzempelikos, A.K. Athienitis, The impact of shading design and control on building cooling and lighting demand, Sol Energy. 81 (2007) 369-382.
[7] U. Rengin, Effect of the facade alternatives on the daylight illuminance in offices, Energ Buildings. 35(2003) 737-746.
[8] J.C. Lam, D.H. W. Li, An analysis of daylighting and solar heat for cooling- dominated office buildings, Sol Energy. 65(1999) 251–262.
[9] P. Ihm, A. Nemri, M. Krarti, Estimation of lighting energy savings from daylighting, Energ Buildings. 44(2009)509-514.
[10] H. Shen, A. Tzempelikos, Daylighting and energy analysis of private offices with automated interior roller shades, Sol Energy. 86(2012) 681-704.
[11] GB, GB50189-2005, Design standard for energy efficiency for public buildings, Ministry of Construction of the People's Republic of China, China Architecture and Building Press, Beijing, 2005.
[12] J.H. Yu, C.Z. Yang, L.W. Tian, Low-energy envelope design of residential building in hot summer and cold winter zone in China, Energ Buildings. 40 (2008) 1536–1546.